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While performing demanding physical activity for long durations, fluid and electrolyte imbalance is common in athletes, military personnel, and recreational hikers. The military and civilian communities have introduced extensive heat mitigation measures to manage heat strain and reduce the risk of serious exertional heat illnesses (EHI). These heat mitigation measures include fluid and electrolyte replacement guidelines, vigilance, and identifying high-risk individuals. Despite these measures, exercise in hot weather continues to result in preventable injuries and deaths in young, healthy individuals. With existing emphasis on appropriate fluid intake during exercise for the avoidance of dehydration, heat illness, and associated performance decrements, there has been a subsequent increase in reported exertional hyponatremia (HYPO) cases related to excessive water intake, elevated sweating rates, excessive sodium losses in sweat, and inadequate sodium intake in soldiers (1), athletes (2,3,4), and recreational hikers (5,6). The primary purpose of this article is to systemically examine the epidemiological literature of fluid and electrolyte imbalances that

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Exertional Heat Illness and Hyponatremia: An Epidemiological Prospective

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CARTER, R. Exertional heat illness and hyponatremia: an epidemiological prospective. *Curr. Sports Med. Rep.*, Vol. 7, No. 4, pp. S20–S27, 2008. *In active populations, heat illness remains a cause of exercise-related injury and death. There is evidence that hyponatremia also occurs, but less often than heat illness. Incidence rates of these conditions are determined by the population at risk and individual susceptibilities. Improved strategies are needed to identify high-risk individuals who are likely to develop either hyponatremia or heat illness.*

INTRODUCTION

While performing demanding physical activity for long durations, fluid and electrolyte imbalance is common in athletes, military personnel, and recreational hikers. The military and civilian communities have introduced extensive heat mitigation measures to manage heat strain and reduce the risk of serious exertional heat illnesses (EHI). These heat mitigation measures include fluid and electrolyte replacement guidelines, vigilance, and identifying high-risk individuals. Despite these measures, exercise in hot weather continues to result in preventable injuries and deaths in young, healthy individuals.

With existing emphasis on appropriate fluid intake during exercise for the avoidance of dehydration, heat illness, and associated performance decrements, there has been a subsequent increase in reported exertional hyponatremia (HYPO) cases related to excessive water intake, elevated sweating rates, excessive sodium losses in sweat, and inadequate sodium intake in soldiers (1), athletes (2,3,4), and recreational hikers (5,6). The primary purpose of this article is to systemically examine the epidemiological literature of fluid and electrolyte imbalances that occur during physical activity. The secondary purpose of this article is to examine signs and symptoms of HYPO and EHI cases from the literature (1,2,5,7–26) and the U.S. Army Research Institute of Environmental Medicine (USARIEM) Total Army Injury and Health Outcomes Database (TAIHOD). While it is acknowledged that the populations at risk for HYPO and EHI may differ, reasonable comparisons are made by examining incidence rates to better understand relative magnitude of each condition. It has been reported that these two conditions have several overlapping clinical features, which has led to misdiagnosis in some rare cases. This article is not intended to persuade the reader of the relative importance of either condition.

OBSERVATIONAL STUDIES OF WATER INTAKE DURING EXERCISE

Many of the recent studies examining water intake during exercise have been observational in nature, with much attention focused upon HYPO (2,3,6,27,28). Given the acute development of EHI and HYPO during exercise, observational field studies provide some unique aspects, since inducing these conditions in a laboratory setting is unethical (29). One important advantage of observational studies to address questions related to water intake during exercise is that they allow for the calculation of incidence and prevalence rates as well as information to generate additional hypotheses regarding medically related issues, risk factors, and behaviors of the individuals performing these activities. However, very few studies in the literature provide epidemiological data on both HYPO and EHI incidence in the same setting.

One disadvantage of observational studies is that they are more susceptible to confounding and sampling bias.

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Furthermore, it is difficult to establish causal links between variables with the use of observation studies. The lack of control in this type of study design suggests there is always a possibility that some unknown factor is exerting influence upon the outcome (29).

Case reports are not very helpful in estimating the extent of EHI and HYPO within a population. In fact, published case reports or media reporting of high-profile athletes or individuals who develop an illness (*i.e.*, heat stroke) can have a profound impact upon perceptions, medical advice, and future behaviors of individuals performing similar athletic events or recreational activities. However, case reports are very reliable when characterizing clinical symptoms and signs and often provide detailed information that is not available in large observational or cross-sectional studies.

Throughout this article, incidence rates are calculated or reported as time or person-time, whenever possible. Incidence is the rate at which new events (*i.e.*, EHI, HYPO, or exercise-induced dehydration) occur within a population at risk. The numerator is the number of new events (*e.g.*, hyponatremia) arising in a specified time period. The denominator is the population at risk (*e.g.*, marathon participants) of an event during this time period. Incidence rates are sometimes expressed as person-time, but often expressed as X cases per a given population base (*e.g.*, per 1000 or 100,000 participants). The use of person-time as opposed to only "time" enables the investigator to handle situations where there are multiple drop-outs in a study or where researchers have not been able to follow an entire population at risk. Using person-time calculations, the follow-up period does not have to be the same for all persons studied. Person-time for a population is the sum of the times of follow-up for each individual within a given population.

DEFINTIONS OF EHI AND HYPO

Minor Heat Illnesses

Minor heat-related illnesses include heat cramps and heat syncope. *Heat cramps* are associated with intense muscle spasms, typically of the leg, arm, and abdominal areas. Heat cramps are believed to result from fluid and sodium deficits and occur mostly in persons with lack of heat acclimatization. *Heat syncope* results from excessive pooling of blood to the skin and extremities and occurs mostly in dehydrated and inactive persons with lack of heat acclimatization.

Serious Heat Illnesses

Serious heat illnesses represent a continuum on the severity scale and include heat exhaustion, heat injury, and heat stroke (30). These serious heat illnesses have many overlapping diagnostic features. *Heat exhaustion* is a mild to moderate illness characterized by an inability to sustain cardiac output with moderate (>38.5°C, 101°F) to high (<40°C, 104°F) rectal temperatures. It is frequently accompanied by hot skin and dehydration. *Heat injury* is a moderate to severe illness characterized by organ (*e.g.*, liver, renal) and tissue (*e.g.*, gut, muscle) injury, with high core temperatures usually but not always greater than 40°C (104°F). *Heat stroke* is a severe illness characterized by severe central nervous system dysfunction, with high core temperatures usually but not always greater than 40°C (104°F). Conversely, individuals with a rectal temperature greater than 40°C universally do not have a heat injury or heat stroke (29); the entire clinical picture including mental status and laboratory results must be considered together. Individuals with heat stroke have profound neuro-cognitive impairments that present early and universally. In addition, heat stroke can be complicated by liver damage, rhabdomyolysis, disseminated intravascular coagulation (DIC), water and electrolyte "imbalances," and renal failure.

Exercise-Induced Hyponatremia

HYPO is defined as decreased blood sodium levels, either caused by overhydration, inadequate sodium intake, or excessive losses in sweat (31); medical problems can result in edema (cerebral or pulmonary) and death in rare cases. Clinically significant HYPO is defined as blood sodium less than 130 $mmol{\cdot}L^{-1}$ (3).

EPIDEMIOLOGY OF EXERTIONAL HEAT ILLNESSES

Most of the epidemiological studies of EHI in the literature are from military populations (*i.e.*, Army, Air Force, and Marines) and have focused on specific bases for relatively brief periods and with relatively small populations (10,32). Recently, Carter and colleagues documented 5246 EHI hospitalizations and 37 heat stroke deaths in the U.S. Army from 1980 through 2002 (33). They showed that heat stroke hospitalization rates increased five-fold (1.8 per 100,000 persons in 1980 to 14.5 per 100,000 persons in 2001). The reasons for this dramatic increase in heat stroke hospitalizations are unclear. Since 2003, recent deployments to hot regions of the world have resulted in significant increases in both hospitalizations and outpatient care for EHI, and at least six heat-related deaths have been reported (unpublished data from the Defense Medical Surveillance System).

Previously, Gardner and colleagues reported that in the U.S. military, 12% of exercise-related deaths are attributed to EHI (32). Smalley and colleagues report that 51 cases (1.3 per 1000 persons) of EHI occurred among basic trainees at Lackland Air Force Base (LAFB) in 1999. In addition, they document seven heat stroke deaths among LAFB trainees from 1956 to 1999 (34). Of the 217,000 Marine recruits that trained from 1982 to 1991, 1454 individuals suffered EHI, which is believed to be one of the highest incidence rates (67 per 1000 persons) among the military services (35).

Exertional Heat Illness in Athletes

Numerous studies have demonstrated that EHI is a major risk for competitive athletes exercising in hot weather conditions (36,37). However, most studies of EHI in athletes have focused only on mortality and do not have sufficient information to calculate incidence rates. Previously, Cooper and colleagues evaluated EHI among American collegiate football athletes during a 3-month period (August–October). They reported a total of 139 EHI and an incidence rate of 4.19 per 1000 athlete exposures (AEs) with no cases of heat stroke or hyponatremia (38). The National Collegiate Athletic Association reported on the 2003–2004 football season with incidence rates of 0.18 per 1000 AEs and 0.01 per 1000 AEs for heat exhaustion and heat stroke, respectively. However, only cases severe enough to miss a practice session were reported. Recently, a 3-yr longitudinal study of 60 collegiate football programs throughout the United States reported 542 cases of EHI with an all-cause EHI rate of 1.50 per 1000 AEs. Specifically, the EHI rate for heat cramps was 1.15 per 1000 AEs, heat syncope was 0.10 per 1000 AE, and heat exhaustion was 0.25 per 1000 AEs (39). During the 1996 U.S. Olympic Track and Field Trials (Atlanta, GA) and the Atlanta Olympic Games, EHI incidence rates were 2.84 per 1000 AEs and 2.93 per 1000 AEs, respectively (40).

EHI can often occur among athletes competing in long-distance running events and race-walking events. These athletes collectively accounted for 30.6% (19/62) at the U.S. Olympic Trials and 52.9% (62/117) of the total EHI cases at the Atlanta Olympic Games (40). Many studies have reported the occurrence of serious EHI during long distance running events, but are not sufficient to calculate incidence rates.

Several studies have shown that EHI and heat stroke deaths also can occur among youth athletes (41,42). The National Center for Catastrophic Sport Injury Research Web site (www.unc.edu/depts/nccsi/) documented that more than 90 high school football players died of EHI between 1955 and 2005, and three heat stroke deaths occurred in 2006. During the USA Cup Soccer Tournament, it was reported that the incidence rate of EHI was 2.8 per 1000 player-hours (41). Another observational study examined 3028 athletes who participated for 7 d in 13 different sports at 8 separate sites during the 1985 Junior Olympic Games in Iowa City. During this event, EHI accounted for 17% of the 121 medical events serious enough to remove an athlete from competition (42). Taken together, these studies demonstrate that young, healthy athletes in many high-intensity sports are at significant risk for EHI.

Exertional Heat Illnesses during Recreational Activities

Studies of EHI occurrence during recreational activities and noncompetitive athletic events are limited; however, available evidence suggests that in particular, inexperienced participants can be at significant risk for EHI. Townes and colleagues examined injuries and medical treatment during a multi-day recreational bike tour and reported that 85 of the 2100 individuals (41 per 1000 persons) who participated were treated for dehydration and EHI (43). Another study reported that 117 of the 2650 participants (44 per 1000 persons) in the California AIDS ride were treated for EHI (44). Backer and colleagues conducted a retrospective analysis of desert hikers (~250,000 persons per year) that needed medical treatment in Grand Canyon National Park. They showed that 109 of the 116 individuals who required medical attention were treated for EHI (6). In the Grand Canyon National Park, the incidence rate of EHI in desert hikers range from 3 to 4 per 1000 persons. Furthermore, one to three heat stroke cases occur each summer, and heat stroke is the second leading cause of death (5).

Risk Factors for Exertional Heat Illnesses

It is accepted widely that EHI does not have a causal relationship with any one factor and that a variety of individual factors, health conditions, medications, and environmental factors can modify an individual's risk for serious EHI (Table 1). Furthermore, it should be noted that not all risk factors can be applied across populations. In some cases, risk factors may be unique to a given population (*e.g.*, members of the military, hikers, or athletes) and may change with time. Serious EHI occurs not only in high-risk populations but in low-risk populations who take appropriate precautions and are exposed to conditions they have been exposed to many times before. This suggests that some victims are inherently more vulnerable on a specific day, or some unique event triggered EHI or abnormal rectal temperature responses (8).

Historically, such unexpected EHI cases were attributed to dehydration (which impairs thermoregulation and increases cardiovascular strain), but it is now suspected that a previous event (*e.g.*, sickness or injury) can make an individual more susceptible to serious heat illness (8). One theory is that previous heat injury or illness might prime the acute phase response and augment the hyperthermia of exercise, thus inducing unexpected serious heat illness (30). Figure 1 illustrates an example in which thermoregulatory responses were altered by an acutely occurring medical condition

TABLE 1
Risk factors for exertional heat illnesses.

Transient Conditions
Situational
Lack of heat acclimation
Low physical fitness
Excessive body weight
Dehydration
>1-h aerobic intense exercise
Alcohol
Peer pressure/motivation
Medical
Febrile illness
Gastroenteritis (diarrhea, emesis)
Self-medication (prescription, recreational drugs, ergogenic stimulants)
Sickle cell trait
Inflammation
Malignant hyperthermia
History of heat-related injury
Environmental
Prolonged heat waves
High daily temperature + humidity

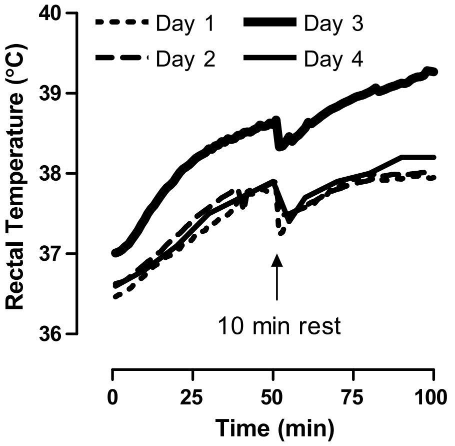

Figure 1. Idiosyncratic hyperthermia observed in association with infection. A U.S. Army soldier with no history of heat illnesses was involved in a study requiring 5 d of heat acclimation/familiarization (6). The environmental chamber temperature was 40°C, relative humidity was 20%, and the wind velocity was 1 m·sec^{-1}. The volunteer exhibited normal rectal temperature to the 100-min exercise bout in the heat on d 1 and 2. On d 3, the volunteer reported for testing with a slight elevation in resting rectal temperature of 37.1°C compared with 36.6°C on the previous 2 d, all of which are within normal range. Later, a diagnosis of cellulitis was given for a blister. The volunteer was prescribed 14 d of oral antibiotic therapy. Nineteen days later, the volunteer continued participation in the study and walked in the heat for the fourth time with physiological responses similar to d 1 and 2, weeks earlier (8).

(*i.e.*, local infection). A U.S. Army soldier's rectal temperatures in response to walking in the heat on the day after diagnosis of an infected blister (cellulitis) were abnormally elevated. Another theory is that prior infection can produce pro-inflammatory cytokines that deactivate the cells' ability to protect against extremely high temperatures.

Most cases of EHI occur during summer months across populations (military, athletes) (33,36). EHI incidence rates can vary from year to year, but more often occur when the weather is the hottest. In general, not being heat acclimatized has been identified as an important factor for heat intolerance and heat illness across populations.

Heat stroke fatalities in U.S. football and military have been speculated to be caused, in part, by increased use of nutritional supplements. However, delayed or improper treatment is the likely major cause of many fatalities (36). The use of stimulants (*e.g.*, ephedra, cocaine, heroin, and methamphetamine) has been associated as a risk factor in EHI. Stimulants increase heat production and may impair heat dissipation, thus elevating core temperature (17).

Body mass index (BMI) and poor fitness are also important risk factors for occurrence of EHI in military personnel, recreational hikers (5,6), and athletes. Marine Corps recruits increase their risk for EHI by three-fold with either a BMI of greater than or equal to 22 kg·m^{-2} or a 1.5-mile run-time of more than 12 min (32). Furthermore, in recruits with both high body mass and slow running times, risk increased more than eight-fold.

Several genetic disorders may modify the risk of EHI (14,45,46). Case reports suggest that sickle cell trait (SCT) may increase the risk of serious EHI (46). SCT is more prevalent in African and certain Asian populations and these populations are at increased risk if they also are of poor physical condition, dehydrated, and exposed to environmental stress (14). Erythrocyte sickling can reduce blood flow and oxygen-carrying capacity of red blood cells and lead to endothelial damage, intravascular coagulation, and local tissue damage due to hypoperfusion (46). Persons with susceptibility for malignant hyperthermia (MH) may be at greater risk for EHI (45).

EPIDEMIOLOGY OF EXERTIONAL HYPONATREMIA

Recent studies have documented that HYPO is a potentially life-threatening medical situation occurring during exercise in otherwise healthy individuals (2–4,6,29). Populations with a low to moderate risk for HYPO include the military communities and recreational hikers (6), whereas individuals engaged in marathon running and ultra-endurance events are at far greater risk. The first published report of HYPO appeared in the literature over 20 yr ago (2). Since that time, several case reports, case series, and cross-sectional (observational) studies (3,4) have been published, with the majority of them from endurance running events and military populations (16). Recently, one study reported the occurrence of HYPO in desert hikers (Grand Canyon) (6). The reported incidence rate of HYPO was low (0.02 to 0.4 per 1000 persons), and no deaths were reported (5).

Hyponatremia during Athletic Events

Several studies suggested that endurance athletes commonly develop asymptomatic HYPO at the end of the event (3,4,29). However, given the large number of endurance race participants each year, the incidence of clinically significant HYPO is likely in the range from 1 to 3 per 1000 persons. The actual mortality rate of HYPO is not known but is likely to be very low.

Much attention related to HYPO has been directed to drinking guidelines and advice for athletes by the medical and science communities as the casual factor for increased HYPO incidence (31). Nevertheless, recently marathons and ultra-endurance competitions have seen a huge influx of inexperienced participants, which has been shown to be the population more likely to experience HYPO (27). In the United States alone, there were more than 20 inaugural marathons in 2003. Furthermore, with the growth of participants in these competitions has been a parallel increase in the number of water stops (28). All of these factors must be considered when examining the casual pathway of HYPO.

Hyponatremia (water intoxication) during endurance exercise was first described by Noakes and colleagues (2) and has been further investigated recently (3,4). A cross-sectional analysis involving a subset of runners (N = 488) from the 2002 Boston Marathon found the incidence of HYPO at 13% (defined as serum sodium = 135 mEq·L^{-1}). The authors also reported that 0.6% of runners developed severe HYPO (defined as serum sodium = 120 mEq·L^{-1}); however, the majority of them were mildly symptomatic or asymptomatic, and several runners failed to complete the event (27). A prospective study from the New Zealand Ironman triathlon found the incidence of HYPO (serum sodium < 135 $mEq \cdot L^{-1}$) to be 18% (40). In that study, 12% of the athletes with HYPO were reported to be symptomatic for HYPO (4). An observational, retrospective study involving 5082 participants from the Houston Marathon reported an incidence rates of HYPO in general (defined as serum sodium = 135 $mEq \cdot L^{-1}$) of 4.1 per 1000 persons (N = 22) and 0.4 per 1000 persons (N = 2) for severe HYPO (defined as serum sodium = 120 $mEq \cdot L^{-1}$) (47).

A retrospective analysis of 2135 participants from eight endurance events found an incidence rate of clinically significant HYPO (serum sodium = 130 $mEq \cdot L^{-1}$) at 14 per 1000 persons (3). Studies from other endurance events have reported incidence rates of HYPO as high as 29%; however, these studies likely suffer from sampling bias and overestimate the "true" nature of the problem (28). Furthermore, most of the HYPO studies are based upon participants seeking medical treatment or taken from participants with symptoms, which likely do not represent the entire competing population. Taken together, these studies suggest that asymptomatic or mild HYPO can be a common occurrence in endurance sports and marathons, but severe, clinically significant HYPO likely occurs less often, and deaths are rare (nine cases reported worldwide since 1985).

Hyponatremia in Military Populations

Several investigations of HYPO in the military were conducted, mainly in response to a cluster of serious HYPO cases and deaths that were reported in 1989 and 1996 (32). In 1997, five cases of serious hyponatremia and one death occurred during U.S. Army training in the southern United States. However, death related to HYPO is extremely rare, and the incidence rate of HYPO across the U.S. Army population has been less than 1 per 100,000 persons for the past 10 yr (33). Furthermore, data from the Defense Medical Surveillance System, which report hospitalizations and ambulatory clinical visits, provid evidence that the incidence rate of HYPO is 0.01 to 0.03 per 1000 person-years across all U.S. military populations (1997–2005). Taken together, these data suggest that clinically significant HYPO is not a major problem in the U.S. military. Thus the cluster of severe HYPO cases and deaths that were reported previously are likely not caused by widespread problems within the military community.

Risk Factors for Exertional Hyponatremia

The three risk factors for HYPO consistently reported in observational studies, case reports, and case series are significant weight gain (fluid retention) during the event, longer finishing times, and BMI of less than 20 (Table 2) (27). Although the incidence rate at which women develop HYPO is higher than men, several studies have shown that this sex difference is a function of smaller body size and longer racing time. Thus, women have increased time to drink with lower fluid requirements (3,4,27). The most important factor in HYPO development is excessive fluid consumption for an individual's fluid needs (2,3,16), not the composition of beverage consumed. However, for long endurance events like Ironman competitions, a sports drink can delay significantly or prevent HYPO from occurring (31).

It also has been suggested that nonsteroidal anti-inflammatory drugs (NSAID) are related to HYPO (28); however, no evidence yet has found a biological plausibility for this relationship. Furthermore, a recent large observational study shows that the prevalence of NSAID use was similar among HYPO and non-HYPO participants (27).

Extreme environmental conditions (hot, humid, and abnormally cold) also may be contributing factors to HYPO (4,6,27). These conditions can influence physiological responses (*i.e.*, sweating) to exercise (31) and drinking behavior of individuals. Recently, increased availability of drinking stations at athletic competitions and preexercise overhydration also have been suggested to contribute to HYPO incidence (28).

EXERCISE EPIDEMIOLOGY: ROLE OF DEHYDRATION

Exercise-induced dehydration has been shown to be associated with an increase in thermoregulatory strain leading to reduced exercise performance, one of several factors involved in EHI (33,36), and associated with HYPO in some rare cases (31). Although there are well-controlled laboratory data demonstrating that dehydration can have adverse physiological affects during exercise, relatively few studies report incidence rates of dehydration during athletic competitions (48) and military deployments or training-related activities (33).

In general, data sufficient to calculate incidence rates are lacking; however, some data are available, which allow for investigation of this important question. Cheuvront and Haymes reviewed the extent of dehydration measured in numerous studies of marathon runners (N > 400). They show that dehydration in these runners ranges significantly (−1.2% to −6.4% decrease in body weight) (48). Although this review of the literature provides important information regarding observed fluid losses in many marathon runners, most of the studies reviewed by Cheuvront and Haymes provide only group means, and denominators were not available to calculate incidence rates (48).

Recently, Noakes and colleagues examined pooled data from eight endurance competitions (distances ranging from 42 to

TABLE 2
Risk factors for exertional hyponatremia.

Individual Factors
Overdrinking
Exercise duration (>4 h continuous physical activity)
Low body weight (<20 BMI)
Women (small stature)
Preexercise overhydration
Excessive Na+ losses (sweat)
Insufficient Na+ in food consumption
Fluid retention

228 km) and reported body weight and blood sodium changes. They showed that 1077 of 2135 (504 per 1000 persons) athletes were more than 2% dehydrated (3). Speedy and colleagues previously reported plasma sodium and body weight changes in 330 ultra-endurance athletes and demonstrated that the majority of those athletes had significant body weight losses and elevated plasma sodium levels (4). However, given the nature of the ultra-endurance and multi-day competitions, body weight measurements may not reflect only fluid balance alterations, but also food intake habits and nonspecific exercise-related gastrointestinal complications (*i.e.*, vomiting and diarrhea) (24,49).

Significant dehydration during exercise also has been reported in non-athletic populations. Carter and colleagues report that the prevalence of dehydration in military EHI cases ranges from 25% to 30% (33). Heat exhaustion with dehydration is the most common form of heat illness seen among hikers in the Grand Canyon (6). Taken together, these data support that the occurrence of dehydration in endurance competitions, desert hikers, and in military populations is very common. It is likely that the dehydration that occurs during exercise, especially in hot environments, in part contributes to reduced exercise performance, early fatigue, and increased EHI risk.

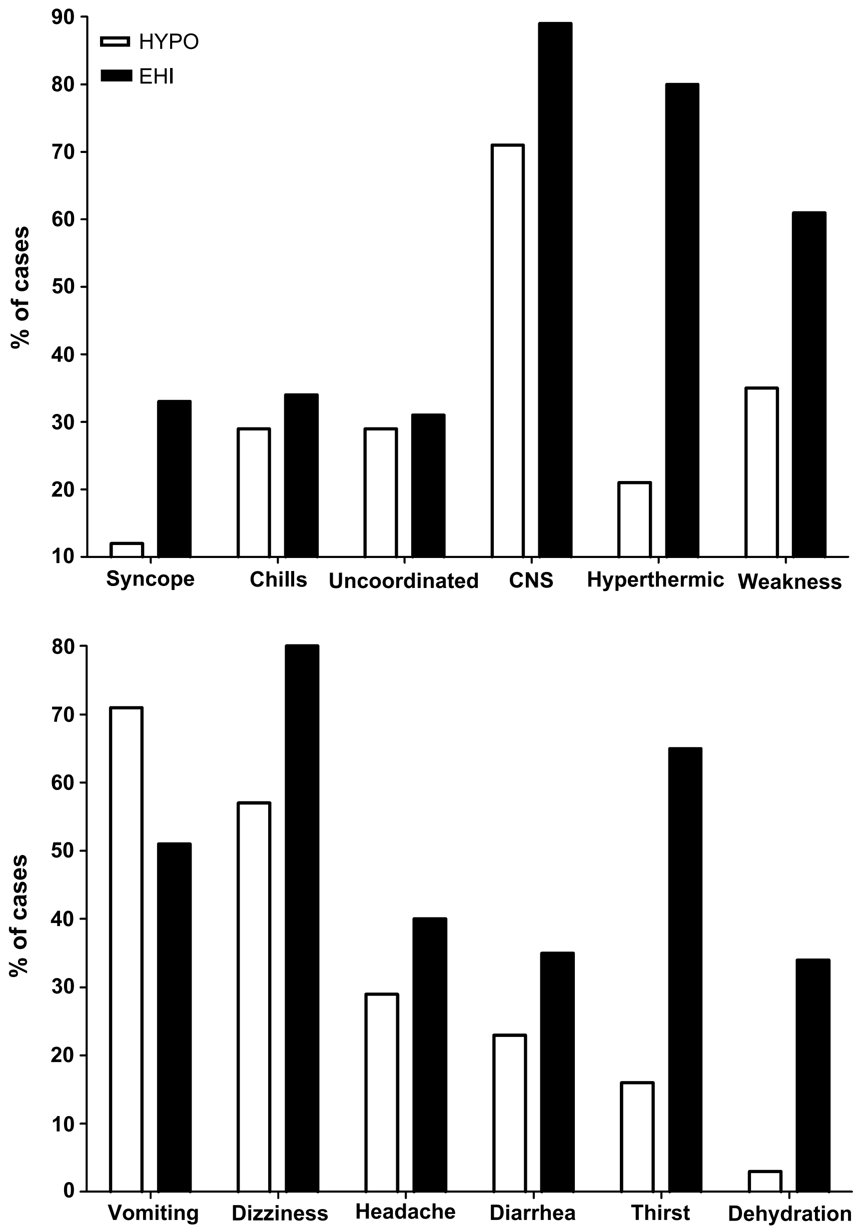

Figure 2. Frequency of signs and symptoms in EHI and HYPO cases reported in the open literature. The percentage of cases with most commonly reported signs and symptoms of EHI (N = 74) and HYPO (N = 34) cases from the open literature (1,2,5,7–13,15–23,25,26) and from the TAIHOD. Other signs and symptoms reported for EHI include dilated pupils, abnormal eye movement (ocular deviation), spontaneous hand movements, aggressive or irrational behaviors, spontaneous nose bleeding, postexercise muscle cramping, and hyperventilation. The symptoms and signs defined as CNS dysfunction include all reports of altered consciousness, coma, convulsions, disorientation, decreased mental status, and apathy. Hyperthermia is defined as rectal temperature higher than 40°C.

THE BURDEN OF DIAGNOSIS: SIGNS AND SYMPTOMS

It has been reported that HYPO and EHI have many common signs and symptoms, which can lead to delayed diagnoses or misdiagnoses in some cases (6,16,28,36). Many studies report signs and symptoms of HYPO and EHI; however, how often these signs and symptoms are consistently observed in presenting cases has not been well described. Figure 2 illustrates the percentage of cases with most commonly reported signs and symptoms of serious EHI (N = 74) and HYPO (N = 34) cases from the literature (1,2,5,7–13,15–21,23,25,26) and from the U.S. Army Research Institute of Environmental Medicine (USARIEM) Total Army Injury and Health Outcomes Database (TAIHOD). Other signs and symptoms reported for EHI and HYPO but not included in the analysis include dilated pupils, abnormal eye movement, spontaneous hand movements, aggressive or irrational behaviors, spontaneous nose bleeding, and postexercise muscle cramping. The symptoms and signs collectively defined as CNS dysfunction include all reports of altered consciousness, coma, convulsions, disorientation, decreased mental status, and apathy. Hyperthermia was defined as a rectal temperature higher than 40°C.

Unfortunately, due to multiple overlapping features, differential diagnosis based upon only signs and symptoms may be challenging. The early signs of clinical EHI and HYPO may be nonspecific. Additional information such as rectal temperature, laboratory values (*i.e.*, blood sodium, urine, or blood osmolality), and knowledge of fluid intake patterns may be needed to confirm diagnosis. Although most cases of EHI reported rectal temperatures over 40°C, in some cases lower values were reported.

It should be noted that self-reported fluid intake alone should not be used for diagnosis of HYPO, since individuals are commonly inaccurate at estimating previous fluid intake. For example, one patient self-reported drinking 3 L of water over a 7- to 8-h period when exposed to ambient temperatures as high as 112°F, which alone may propose dehydration or EHI. However, further medical evaluation found that the patient's blood sodium value was 126 $mEq \cdot L^{-1}$ with a measured rectal temperature of 96.5°F (5).

The signs and symptoms of EHI and HYPO are related to the differential physiological affects of water and sodium imbalance on cardiovascular, neurological, gastrointestinal, skin, and renal function and may present with significant variability. The effects of water and electrolyte imbalance upon these systems are unique to individual cases and can be complicated by multi-system dysfunction, which can be common among severe cases of HYPO and EHI. The presentation of signs and symptoms are also related to many other factors such as weather conditions, severity of illness, timing of diagnosis, and duration of exposure.

CONCLUSION

A review of the literature verifies that EHI remains a common cause of injury in athletes, military personnel, and during a variety of recreational activities (*i.e.*, biking, desert hiking), and deaths are not so uncommon. The reported incidence of EHI is determined by a host of factors, including the definition of EHI, the target population, and individual susceptibility. There is evidence that HYPO occurs in endurance athletes, military personnel, and recreational activities with a small percentage of severe cases, and death is very rare. Most cases of HYPO are likely due to overdrinking, which is influenced by individual variability for required fluid intake. In addition, a host of other individual and environmental factors are in the casual pathway to include inexperience with selected athletic competitions and recreational activities (*e.g.*, desert hiking).

The signs and symptoms have considerable overlap, but with vigilance by well trained medical personnel, a correct diagnosis is highly achievable. Despite substantial interests in EHI and HYPO, more work is required to determine the true occurrence of these medical conditions in populations at risk. Moreover, better measures and prevention strategies are needed to reduce the incidence rates of both HYPO and EHI.

Additional studies are needed to examine incidence rates and risk factors of both HYPO and EHI across diverse populations. Furthermore, longitudinal studies are needed to examine trends in incidence and prevalence of EHI, dehydration, and HYPO, in particular across athletic and recreational settings.

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Disclaimer: The views expressed in this article are those of the authors and do not reflect the official policy of the Department of the Army, Department of Defense, or the U.S. Government.

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